

GEOLOGY AND GEOPHYSICS



Mount Erebus on Ross Island, Antarctica's most active volcano, is the continent's only one with a persistent convecting lake of molten, alkali-rich phonolitic magma in its summit crater. This makes it one of the few volcanoes on Earth with nearly continuous, small explosive activity and continuous internal earthquake activity. Because of this, Mount Erebus provides the ideal natural laboratory to study certain phenomena with volcanoes and volcanic activity. *(NSF/USAP photo by Josh Landis)*

Antarctica is not only one of the world's seven continents, it also comprises most of one of a dozen major crustal plates, accounting for about 9 percent of the Earth's continental (lithospheric) crust. Very little of this land is visible, however, covered as it is by the vast East Antarctic Ice Sheet and the smaller West Antarctic Ice Sheet. These ice sheets average some 3 kilometers deep and form a virtual vault; 90 percent of the ice on Earth is here. And it is heavy, depressing the crust beneath it some 600 meters (m). These physical characteristics, while not static, are current. Yet Antarctica is also a time machine, thanks to the sciences of geology and geophysics, powered by modern instruments and informed by the paradigm of plate tectonics/continental drift.

Geologists have found evidence that there was once a forested supercontinent, which they call Gondwanaland, in the Southern Hemisphere. Before the Earth's constantly shifting plate movement began to break the continent up 150 million years ago, Antarctica was a core piece of this assembly; the land adjoining it has since become Africa, Madagascar, India, Australia, and South America. Though the antarctic plate has drifted south only about a centimeter a year, geologic time eventually yields cataclysmic results. The journey moved the antarctic plate into ever colder, high-latitude climates, at a rate of about 4°C for each million years; eventually conditions changed dramatically, and Antarctica arrived at a near polar position. This astounding story-written in the language of rock and fossils-is locked in beneath the ice and the sea, and in the bedrock below them both.

As the ice sheets developed, they assumed, through their interaction with oceanic and atmospheric circulation, what has become a key role in modulating global climate. As a bonus, the South Pole presents a strategic point to monitor the Earth's seismic activity. Antarctica is the highest continent on Earth (about 2,150 m above sea level), with its fair share of mountains and volcanoes; thus, many generic questions of interest to Earth scientists worldwide also apply to this region. Some specific issues of interest to the Geology and Geophysics program include the following:

- determining the tectonic evolution of Antarctica and its relationship to the evolution of the continents from Precambrian time (600 million years ago) to the present;
- determining Antarctica's crustal structure;
- determining how the dispersal of antarctic continental fragments may have affected the paleocirculation of the world's oceans, the evolution of life, and the global climate (from prehistoric times to the present);
- reconstructing a more detailed history of the ice sheets, identifying geological controls to ice-sheet behavior, and defining geological responses to the ice sheets on regional and global scales; and
- determining the evolution of sedimentary basins within the continent and along the continental margins.

These issues will all become clearer as scientists improve their models of where, when, and how crustal plate movement wrought Antarctica and its surrounding ocean basins. The Geology and Geophysics program funds investigation into the relationships between the geological evolution of the antarctic plate and the life and processes that can be deduced to accompany it-the paleocirculation of the world's oceans, the paleoclimate of the Earth, and the evolution of high-latitude biota. A current emphasis is the West Antarctic Ice Sheet program, focused on the smaller of the continent's two ice sheets and conducted jointly with the Glaciology program. Several important research support activities are underway as well:

- **Meteorites:** In a partnership with the National Aeronautics and Space Administration and the Smithsonian Institution, the program supports meteorite collection through the antarctic search for meteorites (ANSMET) and chairs an interagency committee that is responsible for curating and distributing samples of antarctic meteorites.
- **Mapping and geodesy:** In partnership with the U.S. Geological Survey, the program supports mapping and geodetic activities as an investment in future research in earth sciences. The U.S. Antarctic Resources Center (USARC) constitutes the U.S. Antarctic Program's contribution to the Scientific Committee on Antarctic Research library system for earth sciences information; housed here is the largest collection of antarctic aerial photographs in the world, as well as many maps, satellite images, and a storehouse of geodetic information.
- **Marine sediment and geological drill cores:** In partnership with the Antarctic Marine Geology Research Facility at Florida State University, the program manages and disseminates marine sediment and geological drill cores mined in Antarctica. The collection includes an array of sediment cores as well as geological drill cores from the Dry Valley Drilling Project, the Cenozoic Investigations of the Ross Sea drilling program, and the Cape Roberts Drilling Project. The facility fills requests for samples from researchers worldwide and also accommodates visiting researchers working onsite.

Multiple isotope analyses of soil sulfate and nitrate in the antarctic dry valleys.

Huiming Bao, Louisiana State University and Agricultural and Mechanical College, and David Marchant, Boston University.

We will quantify atmospheric deposition of sulfate and nitrate in the dry valleys region of southern Victoria Land and generate the first quantitative model for the origin, distribution, and postdepositional alteration of

atmospheric sulfate and nitrate in dry valley soils. Besides testing the hypothesis that landforms in the dry valleys have been stable for millions of years, our results will provide a valuable reference for quantitative soil development in hyper-arid deserts elsewhere on Earth and on Mars. We will conduct multiple stable isotopic analyses of the water-soluble oxy-anions, sulfate and nitrate, in soils of differing ages and parent materials.

Newly discovered spatial patterns in the oxygen-isotopic composition of sulfate in these soils call for the existence of two sulfate end members, sea-salt sulfate and biogenic sulfate. The latter refers to sulfates formed by the oxidation of reduced biogenic sulfur gases (e.g., dimethylsulfide) in the atmosphere. Isotopic analyses will differentiate between these two forms of sulfate. In addition, preliminary data on the oxygen-isotopic composition of nitrate from these soils reveal exceptionally large nitrate, oxygen-isotopic (O17) anomalies and a spatial pattern that reflects a single nitrate source rather than two, as is the case for sulfate. To quantify long-term atmospheric input of sulfate and nitrate and their subsequent mobility in dry valley soils, we propose to

- sample vertical soil profiles at centimeter- to subcentimeter-scale resolution;
- systematically analyze the oxygen-isotopic composition of sulfate and nitrate;
- examine soils of a wide range of radiometric ages and parent materials, including ancient volcanic ashes, colluvium, lodgement tills, and ice-sublimation tills; and
- construct a simple one-dimensional transport model for sulfate and nitrate in vertical soil profiles.

When combined with our existing chronology of dry valley soils (built up over the past 15 years), these analyses will, for the first time, quantify the rate and style of soil development and patterned ground evolution in the dry valleys. These quantitative data are of paramount importance if we are to advance our understanding of this ecosystem and provide baseline data for anticipated analyses on Martian regolith. (GO-051-O; NSF/OPP 01-25842); NSF/OPP 01-25330)

Antarctic mapping, geodesy, geospatial data, satellite image mapping, and Antarctic Resource Center management.

Jerry L. Mullins, U.S. Geological Survey.

Antarctic mapping, geodesy, geospatial data, satellite image mapping, and the Antarctic Resource Center (ARC) constitute some of the activities necessary for the successful operation of a multifaceted scientific and exploratory effort in Antarctica. Year-round data acquisition, cataloging, and data dissemination will continue in the ARC in support of surveying and mapping. Field surveys are planned as part of a continuing program to collect the ground control data required to transform existing geodetic data into an earth-centered system suitable for future satellite mapping programs and to reinforce extant control of mapping programs to support future scientific programs. Landsat (Land Remote-Sensing Satellite) data will be collected as funding permits to support satellite image-mapping projects. These maps will provide a basis for displaying geologic and glaciologic data in a spatially accurate manner for analysis. They will also support future expeditions by providing a basis for planning scientific investigations and data collection. In addition, spatially referenced digital cartographic data will be produced from published maps.

Geodetic projects are planned as part of a continuing program aimed at building a continent-wide geodetic infrastructure (GIANT) that will support a wide range of U.S. and international scientific research objectives by

- establishing and maintaining a framework of permanent geodetic observatories,
- extending and strengthening the existing network of stations linked to the International Terrestrial Reference Frame,
- establishing geodetic coordinates at identifiable points for georeferencing satellite image- mapping projects,
- maintaining and calibrating tide gauge instrumentation,
- carrying out absolute gravity measurements, the continental margins.
- applying new high-accuracy remote-sensing measurement technologies such as airborne laser altimetry and digital cameras, and
- expanding the online geodetic database with new and historical data.

The geodetic field program is supported by a cooperative arrangement with Land Information New Zealand. (GO-052-M/P/S; NSF/OPP 02-33246)

Stability of land surfaces in the McMurdo Dry Valleys: Insights based on the dynamics of subsurface ice and sand-wedge polygons.

Bernard Hallet, University of Washington.

As concerns grow over warming and the recent occurrence of seemingly extreme weather events, the dynamic nature of climate has received more public attention. In this context, understanding the inherent variability of the Earth's climate and how humans can and do affect the Earth's environment is becoming increasingly important. This project focuses on the landscape features and soils of Antarctica's dry valley region to provide a more complete understanding of past climatic and environmental conditions.

One important means of improving our understanding of the planetary climate system is to use the Earth as a natural laboratory to examine past behavior. One of the most extreme changes in the climate system during the past few million years was the transition from a warm period in the Pliocene to an ice-age world. Scientists believe that during this interval, relatively mild conditions in Antarctica gave way rapidly to intense glacial conditions, catalyzing the growth of what has become the largest ice sheet on Earth. This inference is based on geologic indicators of past climate, from which some scientists suggest that East Antarctica was relatively warm and largely free of glaciers about 3 to 4 million years ago (during parts of the Pliocene). The mild conditions ended abruptly, with rapid ice-sheet growth and development of the very cold, dry climate that now characterizes this region. A contrasting view, based on substantial geologic evidence, suggests that East Antarctica has been cold and the ice sheet stable for at least 8 million years, and perhaps considerably longer. These views lead to drastically different interpretations of the stability of the Earth's climate.

We hope that our research will help resolve this important dilemma by introducing independent new evidence and insights derived from studies of the stability of ground ice and land surfaces in the McMurdo Dry Valleys. We will study modern-day processes that have important implications for understanding the occurrence of

buried ice found recently in Beacon Valley. This specimen may be the oldest ice on Earth; if so, it will provide strong evidence of the long-term stability of the East Antarctic Ice Sheet and may also afford a rare glimpse into atmospheric conditions millions of years ago.

Specific processes to be investigated include

- exchange at the ground surface that affects ground temperature,
- water-vapor transport and other processes leading to the formation or loss of ice in the soil, and
- frost cracking due to contraction during rapid cooling of the frozen ground in the winter and resulting disruptions of the soil. (GO-053-O; NSF/OPP 97-26139)

Response of the East Antarctic Ice Sheet to middle Miocene global change.

David R Marchant, Boston University.

As evidence of global climate change continues to accumulate, scientists concentrate on models that might indicate what impacts such change could have. Among the most important questions is, What could happen to the east antarctic ice sheet? One of the largest known global climate shifts occurred in the Middle Miocene between about 15.6 and 12.5 million years ago. As the isotopic composition of oxygen in the oceans shifted, dramatic global cooling and reorganization of ocean circulation patterns took place. This significant and irreversible shift set the stage for modern oceanic and atmospheric circulation and for the bipolar ice ages that have dominated climate records for the past 12.5 million years. How did Antarctica respond to this great climate shift? Could growth of the antarctic ice sheet have initiated this shift? If so, how might future fluctuations in the volume of ice on East Antarctica influence atmospheric and oceanic circulation?

Recently there was an unexpected breakthrough in antarctic geology: discovery of Miocene-age volcanic ashes interbedded with surficial sediments in southern Victoria Land. These terrestrial deposits provide unambiguous data from which to generate precise climatic and glaciologic reconstructions of how the global climate changed and the ice sheet evolved. This site appears to be the only place in Antarctica where pristine, Miocene-age, unconsolidated deposits are preserved at the ground surface.

These data also permit scientists to address key questions such as,

- What contributing factors in Antarctica led to the abrupt global cooling about 14 million years ago?
- Does the Middle Miocene shift in the isotopic composition of the oceans signify a major expansion of east antarctic ice?
- Or does this isotopic shift instead reflect a change in ocean temperature or circulation?
- And a related question: When did cold, hyper-arid, polar-desert conditions (signifying the development of a polar East Antarctic Ice Sheet) first evolve? In analyzing these deposits, we expect to obtain a precise chronological sequence, based on 50 laser-fusion isotopic analyses of in situ volcanic ashes and 20 cosmogenic, exposure-age analyses of ancient deposits. We also expect to develop a coeval record of

the Miocene paleoclimate, based on textural changes in alpine drifts; the areal distribution of ice-marginal lakes; the abundance of dated, patterned ground and ventifact pavements; and the geochemistry of buried soils and volcanic-ash deposits. (GO-054-O; NSF/OPP 98-11877)

The Ferrar magmatic mush column system, Dry Valleys, Antarctica.

Bruce D. Marsh, Johns Hopkins University.

The Earth's basic structure was formed by processes involving the crystallization of magma (molten rock). Operating on billion-year time scales, these processes have produced a wide diversity of rock types. In turn, these different elements comprise the continents and the ocean basins-the basic surface features of the Earth. Yet many of the details of these physical and chemical processes remain obscure.

Present-day volcanism exemplifies this overall process of differentiation; so many different varieties of lava erupt, yet scientists have not been able to relate this diversity to the prolonged and detailed deep-Earth processes that undoubtedly generate it. Solidified bodies of magma (plutons) that were once deeply buried and are now exposed through erosion also furnish evidence, but most often how these plutons relate to the magmatic-volcanic system is not clear.

This research is pointed at this fundamental problem: we will examine magma crystallization processes by studying sills (magmatic sheets) from the Ferrar Group in Antarctica. These studies should expose the relationship of plutonism to volcanism and may provide some important insights into planetary magmatism. The Ferrar magmatic system of the McMurdo Dry Valleys (Ferrar-DV) exemplifies the emerging global paradigm. Sills occur in stacks, connected below to a deep-seated magmatic source and above to a volcanic center.

The world's major magmatic systems reveal this pattern, since they tend to occur at ocean ridges (e.g., Kilauea, Mount Etna, Stillwater, and Rum, among many others). Only the Ferrar-DV, however, clearly reveals the critical physical and chemical connections between the deep, mush-dominated system and the near-surface, pre-eruptive sill system.

This project seeks to ascertain the full physical and chemical nature of the Ferrar-DV magmatic system, by

- fully delineating its vertical and horizontal extent and explaining how it was established,
- explaining the mechanics of formation of the Dais layered intrusion,
- producing a map of Ferrar rocks throughout the dry valleys, and
- producing a three-dimensional model of the opx tongue and feeder system.

The central science goal is to elucidate a rarely seen transition between plutonic and volcanic systems, one that may have implications fundamental to planetary magmatism. (GO-056-O; NSF/OPP 98-14332)

ANSMET (the antarctic search for meteorites).

Ralph Harvey, Case Western Reserve University.

Since 1976, ANSMET (the antarctic search for meteorites) program has recovered more than 10,000 meteorite

specimens from locations along the Transantarctic Mountains. Antarctica is the world's premier meteorite hunting ground for two reasons:

- First, although meteorites fall at random all over the globe, the likelihood of finding a meteorite is enhanced if the background material is plain and the accumulation rate of terrestrial sediment is low; this makes the East Antarctic Ice Sheet the perfect medium.
- Second, along the margins of the sheet, ice flow is sometimes blocked by mountains, nunataks, and other obstructions; this exposes slow-moving or stagnant ice to the fierce katabatic winds, which can deflate the ice surface and expose a lag deposit of meteorites (a representative portion of those that were sprinkled throughout the volume of ice lost to the wind). When such a process continues for millenia, a spectacular concentration of meteorites can be unveiled.

It is important to continue recovering antarctic meteorites because they are the only currently available source of new, nonmicroscopic extraterrestrial material. As such, they provide essential "ground truth" about the composition of asteroids, planets, and other bodies of our solar system. ANSMET recovers samples from the asteroids, the Moon, and Mars for a tiny fraction of the cost of returning samples directly from these bodies.

During the 2002-2003 field season, ANSMET's main field party (8 people) will visit the Goodwin Nunataks and MacAlpine Hills region near the headwaters of the Beardmore Glacier. Goodwin Nunataks was last systematically searched in the 1999-2000 season, when more than 400 specimens were recovered. About half of the exposed blue ice in this area remains to be searched. MacAlpine Hills was visited in the 1987 and 1988 seasons, with 126 meteorites recovered. This season we hope to complete the systematic searching begun during those previous visits.

A second team consisting of 4 people will be deployed to the Pecora Escarpment region via South Pole Station and will be intensively supported by light aircraft to allow "survey-level" searches of several smaller icefields in the region. In addition to recovering meteorites, the goal for this group will be to identify the potential these icefields hold for more detailed searches during future seasons. (GO-058-O; NSF/OPP 99-80452)

Intrusive architecture and flow directions in southern Victoria Land.

Thomas H. Fleming, Southern Connecticut State University; Stephen Marshak and Alan Whittington, University of Illinois; and Anne Grunow, Ohio State University.

The dispersal of Gondwanaland represents one of the largest breakups of a supercontinent in Phanerozoic times. This breakup was associated with the emplacement of a large Jurassic mafic-igneous province that extended across the Karoo (southern Africa), Ferrar (Antarctica), and Tasman (Australia) regions and comprised continental flood basalts and extensive intrusive dolerites (other igneous rocks). Models linking development of the large (over 3,000 kilometers) Ferrar province to a mantle plume, a major magma conduit, or multiple sources make testable predictions about magma transport patterns within the province.

In our pilot study, we will use several different techniques aimed at evaluating these models and providing a greater understanding of the emplacement mechanisms, flow directions, and magmatic architecture associated with the Ferrar mafic intrusive province in southern Victoria Land. Our research will include mapping intrusive geometry based on structural field studies and geochemical correlation techniques. Further, we will use anisotropy of magnetic susceptibility, as well as mesoscopic and petrofabric flow indicators, to evaluate magma flow directions within the intrusive complex.

The results we will obtain will help resolve remaining questions about the geometry, propagation, and flow patterns in mafic large igneous provinces and provide a deeper understanding of the relationships between mantle plumes, basaltic magmatism, and continental breakup. (GO-062-M; NSF/OPP 01-26106, NSF/OPP 01-25634, NSF/OPP 0125737)

Calibration of cosmogenic argon production rates in Antarctica.

Paul R. Renne, Berkeley Geochronology Center.

We intend to establish the systematics of cosmogenic argon production required to establish its measurement as a routine surface exposure dating tool analogous to existing methods based on helium-3, beryllium-10, carbon-14, neon-21, and aluminum-26. Cosmogenic argon offers advantages over existing cosmogenic chronometers in that it is stable (hence applicable to long-term or ancient exposure dating) and less prone to diffusive loss than helium or neon.

Argon-38 is produced principally by spallation of calcium and (probably) potassium, and it is most easily measured using neutron-irradiated samples, as has been done routinely on extraterrestrial samples for decades. Our initial measurements on antarctic samples demonstrate the viability of this method for terrestrial samples and suggest an average production rate of greater than 100 atoms/gram-calcium/year. Existing data suggest that argon-38/calcium exposure ages younger than 105 years can be accurately determined by this method.

Further work on calcic minerals (apatite, sphene, clinopyroxene, plagioclase, calcite) whose exposure histories are constrained by helium-3 and neon-21 concentration data will be used to determine the calcium-derived production rate. Analogous work on potassium-rich minerals (potassium-feldspars, micas) will be used to constrain the production of argon-38 from potassium, which should theoretically be comparable to that from calcium when the same neutron-activation method is used.

Our analytical work will use existing samples plus new samples to be collected from the dry valleys of Antarctica to maximize cosmic radiation dosage for purposes of calibration. Laboratory studies of the retentivity of argon-38 in appropriate minerals will be used to help evaluate our results and guide future applications. (GO-064-O; NSF/OPP 01-25194)

Improved Cenozoic plate reconstructions of the circum-antarctic region.

Steve Cande, U.S. Air Force Technical Application Center, and Joann Stock, California Institute of Technology.

Well-constrained Cenozoic plate reconstructions of the circum-antarctic region are critical for examining a number of problems of global geophysical importance, among them

- relating plate kinematics to geological consequences in various plate circuits (Pacific-North America, Australia-Pacific);
- understanding what drives plate tectonics (which requires well-constrained kinematic information to distinguish between different geodynamic hypotheses); and
- understanding the rheology of the plates themselves, including the amount of internal deformation they can support and the conditions leading to the formation of new plate boundaries through the breakup of existing plates.

By obtaining better constraints on the motion of the antarctic plate with respect to other plates, and by better quantifying the internal deformation within Antarctica, we can contribute to understanding these fundamental issues.

We will analyze existing data to address several specific issues related to the motion of the antarctic plate. First, we will work on four-plate solutions of Australia-Pacific-West Antarctica-East Antarctica motion to constrain the rotation parameters for separation between East and West Antarctica by imposing closure on the circuit and using relevant marine geophysical data from all four of the boundaries. We will determine the uncertainties in the resulting rotation parameters based on the uncertainties in the data points. These can then be propagated in the plate circuit to address the issues listed earlier. Second, we will further quantify Pacific-West Antarctica rotation parameters for Tertiary time, using recently acquired well-navigated transit data from the icebreaking research ship *Nathaniel B. Palmer*. These parameters and their uncertainties will be used to assess plate rigidity and will be included in the circuit studies.

We will collect new marine geophysical data (on underway gravity, magnetics, and swath bathymetric data) on *Nathaniel B. Palmer* transit cruises. On one of the cruises, we propose to teach a formal class in marine geophysics to graduate and undergraduate students to integrate teaching activities with the data collection objectives. (GO-071-N; NSF/OPP 01-26340, NSF/OPP 01-26334)

Chemical weathering in Taylor Valley streams: Sources, mechanisms, and global implications.

W. Berry Lyons, Ohio State University, and Brent McKee, Tulane University.

Geochemists study the process of "chemical weathering" whereby rocks and minerals are transformed into new, fairly stable chemical combinations, primarily by such chemical reactions as oxidation, hydrolysis, ion exchange, and solution. Silicate hydrolysis is another such process that may have an impact on the global climate by consuming carbon dioxide, an important greenhouse gas. Generally, scientists have concentrated on more temperate climates to examine chemical weathering, because two of its most significant drivers are warmth and humidity.

However, recent data suggest that chemical weathering can and does occur in polar desert streams. At around 78°S, a number of ephemeral streams in Taylor Valley, Antarctica, that are associated with dry-based glaciers flow for 4 to 10 weeks each year. Solutes produced from chemical weathering (such as major cations), minor elements (for example, rubidium, cesium, lithium, strontium, and barium), bicarbonate, and dissolved reactive silica, as well as isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) have been found here. Although the mechanism/process of weathering is unknown, we hypothesize that the high chemical weathering rates that have been computed derive either from the high coincidence of freezing/thawing cycles and/or the unusual hydrologic behavior of the hyporheic zone in these streams.

Building on the initial work of the McMurdo Dry Valleys Long-Term Ecological Research team and others, we hope to better establish weathering rates and weathering mechanisms by examining the cryogenic processes whereby physical weathering may influence chemical weathering. To establish which materials are being weathered, we will analyze the suspended matter (in streams from the Lake Bonney basin in Taylor Valley and the Onyx Valley in Wright Valley) for their bulk chemistry and then compare these data with rock types in the valleys. To better ascertain solute sources, we will focus on uranium series geochemistry. Using major rock types from the Taylor and Wright Valleys, we will also conduct laboratory experiments to establish how microfracturing from freeze-thaw cycles could affect chemical weathering.

All of the data we gather will be used to draw analogies to historic weathering regimes on Earth during colder, drier climatic eras. (GO-074-O; NSF/OPP 00-87915)

Dry Valleys Seismograph Project.

Robert Kemerait, U.S. Air Force Technical Applications Center.

One recurrent issue in seismography is noise; that is, background phenomena that can interfere with clear and precise readings. The Dry Valleys Seismograph Project, a cooperative undertaking with the New Zealand Antarctic Program, was established to record broadband, high-dynamic-range, digital seismic data from the remote Wright Valley, a site removed from the environmental and anthropogenic noise that is ubiquitous on Ross Island.

The Wright Valley site provides one of the few locations on the continent with direct access to bedrock. The station there consists of a triaxial broadband borehole seismometer [100 meters (m) deep] and a vertical short-period instrument at 30 m. The seismological data are digitized at the remote location, telemetered by repeaters on Mount Newall and Crater Hill, and received eventually by the recording computer at the Hatherton Laboratory at Scott Base, where a backup archive is created.

These data will eventually reach the international seismological community; from Hatherton, they pass along a point-to-point protocol link to the Internet at McMurdo Station and thence to the Albuquerque Seismological Laboratory for general distribution. This data set has beautifully complemented the data from other seismic stations operated by the Albuquerque Seismological Laboratory at Amundsen-Scott South Pole Station, Palmer Station, and Casey, an Australian base. (GO-078-O; NSF/OPP-DoD MOA)

The Scotia Arc GPS Project: Focus on the Antarctic Peninsula and South Shetland Islands.

Frederick W. Taylor and Ian Dalziel, University of Texas-Austin.

The principal aim of the original Scotia Arc GPS (global positioning system) Project (SCARP) was to determine motions of the Scotia plate relative to adjacent plates and to measure crustal deformation along its margins with special attention to the South Sandwich microplate and Bransfield Strait extension. Our current research is confined to the part of the SCARP project that includes our GPS sites at Elephant Island, the South Shetland Islands, and the Antarctic Peninsula. The British Antarctic Survey provides data from two sites on the Scotia Arc for our project.

We plan to complete the measurements required to quantify crustal deformation related to the opening of the Bransfield Strait and the South Shetland microplate, and to identify any other independent tectonic blocks that our GPS data may reveal. These measurements will be done using ship support during the 2002-2003 season. Five years have passed since we did our first measurements, and it should be possible to determine quite precise horizontal velocities.

The British Antarctic Survey and the Alfred Wegener Institute have also recognized the importance of the Scotia plate and the Bransfield system. They, too, have used GPS to measure crustal motions in this region and duplicate a number of our sites. We expect to publish a joint paper and, also, to publish our own interpretations and data. Our network has several advantages that justify our collecting another set of data and analyzing it. One is that we have established and measured GPS sites on Smith, Low, and Livingston Islands, where other groups have not. These sites significantly extend the dimensions of the South Shetland microplate so that we can determine a more precise pole and recognize any sub-blocks within the South Shetland arc. Smith and Low Islands are near the end of the Bransfield Basin, where relative motion between the South Shetland microplate must somehow terminate, perhaps by faulting along an extension of the Hero fracture zone. Another advantage is that we conducted our measurements using fixed-height masts that eliminate all but a fraction of a millimeter of vertical error. Vertical motion associated with postglacial rebound should be on the order of several

millimeters per year, which will eventually be measurable. The fact that mid-Holocene shorelines emerged to more than 20 meters on some South Shetland arc islands suggests that vertical motion is significant. (GO-080-L; NSF/OPP 01-26472)

Mount Erebus Volcano Observatory: Gas emissions and seismic studies; Development of integrated seismic, geodetic, and volcanic gas surveillance instrumentation volcanic research; U-series isotopic constraints on the rates of magma genesis, evolution, and degassing at Mount Erebus.

Philip R. Kyle and Richard C. Aster, New Mexico Institute of Mining and Technology; Kenneth W. W. Sims, Woods Hole Oceanographic Institute.

Magmatism is one of the most fundamental dynamic processes of planetary interiors, yet our knowledge of the time-dependent parameters of basalt petrogenesis (solid mantle upwelling rate, melting rate, melt transport rate, magma storage time, and magma recharge rate) is quite limited. Magmatic processes such as melting, fractional crystallization, and magma chamber replenishment can fractionate parent/daughter ratios of U-decay series isotopes and thus create isotopic disequilibrium. Because the half-lives of U-series isotopes are comparable to the time scales of these processes, measurement of this isotopic disequilibrium in volcanic gases and mineral separates provides constraints on the duration and rates of magmatic processes.

Mount Erebus on Ross Island is Antarctica's most active volcano and also the only one with a persistent convecting lake of molten, alkali-rich phonolitic magma in its summit crater. This makes Mount Erebus one of the few volcanoes on Earth with nearly continuous, small explosive activity (two to six Strombolian eruptions daily) and continuous internal earthquake (seismic) activity. As such, it provides the ideal natural laboratory to study certain phenomena, specifically how gas is given off by magma and the seismic activity that results from a convecting magma conduit.

The small Strombolian eruptions eject volcanic bombs, thus providing samples of the magma with large, well-formed crystals. These bombs, plus older radiometrically dated lava flows around the summit of Mount Erebus, provide samples that constitute a unique opportunity to understand the timing of fundamental magmatic and volcanologic processes.

We intend to combine seismic studies and gas emission rate measurements in order to elucidate the nature and dynamics of the magmatic plumbing system, as well as eruptions and degassing from the lava lake. (The eruptions will be captured on video.) The gas studies will provide some of the first data available on carbon dioxide degassing from a highly alkalic magma system. They should also help evaluate how much lead from Mount Erebus (relative to lead released by marine aerosols) gets into the snow on the East Antarctic Ice Sheet and thus shed light on hypotheses about the anthropogenic origins of lead. Further goals of the gas studies are to

- examine the role of Mount Erebus as a source of gas and aerosols for the antarctic environment;
- understand the role of volcanism as a source of carbon dioxide emissions into the atmosphere, especially for highly alkalic magma;
- understand the evolution of the main volatile substances (water vapor, carbon dioxide, total sulfur, fluorine, and chlorine) in the Mount Erebus magmatic system, as well as their role in the eruptive behavior of the mountain; and

- correlate the nature of the gas emissions with the observed seismic activity.

For the seismic studies, we will install five integrated scientific instrument packages, all slightly different, depending on their location. All will include a broadband seismometer and dual-frequency global positioning system (GPS) units with 900 mega-Hertz spread spectrum transceivers to telemeter the data to McMurdo Station. Other equipment will include tiltmeters, infrasonics sensors, meteorological instruments (wind speed and directions, pressure and temperature), infrared radiometers (thermometers), and gas sensors. The packages will be battery powered and have solar panels and wind generators. We will also use GPS geodetic measurements for deformation studies to monitor the movement of magma inside the volcano.

Using U-series isotopes will allow us to examine the time scales of

- magma genesis and melt transport from the mantle,
- magma evolution and crystallization processes during magma storage in the crust, and
- magma degassing and recharge rates into the erupting magma chamber.

This is the first time U-series isotopes have been used in an integrated fashion to examine both gases and the associated magma. We hope to achieve a better understanding of the whole magmatic system, from magma formation by partial melting in the mantle through its evolution and finally to its degassing and open-system behavior in the lava lake.

Project team members will travel by helicopter to a camp at Fang Glacier to acclimatize and from there will go to the Lower Erebus Hut, where the work will be conducted. Travel to the work sites will be by helicopter and snowmobile. Monitoring equipment should ensure a nearly real time flow of data to the New Mexico Institute of Mining and Technology and the University Navstar Consortium.

The resulting data should enhance the collection of earthquakes we are using in a computer model of the interior of the volcano, as well as provide a tool scientists can use for conducting volcano surveillance, monitoring eruptions, and detecting subtle changes in the internal behavior of volcanoes. The broadband data will support a detailed study of the explosion mechanism, especially the very-long-period signals that are emitted. It should also help us detect temporal and spatial variability in earthquake mechanisms, which in turn might provide more insights into how variations in gas emissions could be implicated. (GO-081-O, GO-085-O; NSF/OPP 98-14921, NSF/OPP 01-16577, NSF/OPP 01-26269)

A global positioning system program to monitor motions in the bedrock of the West Antarctic Ice Sheet.

Ian Dalziel and Frederick Taylor, Institute of Geophysics, University of Texas; Robert Smalley, University of Memphis; and Michael G. Bevis, University of Hawaii.

The bedrock that underlies the West Antarctic Ice Sheet is not well described. Without a reliable evaluation of its history-both tectonic and ice-induced crustal motions-we will never be able to fully comprehend its past, present, and future dynamics. Without that knowledge, we can neither develop reliable global change scenarios for the future nor accurately factor the antarctic region into global plate movements. Currently, permanent global positioning system (GPS) networks that measure bedrock movement are established only on the fringe of the West Antarctic Ice Sheet; they cannot provide the data on subglacial volcanism, active tectonics, and ice streaming that are needed.

This project is focused on establishing baseline, long-term, reliable geodetic measurements of the crustal motion in the bedrock beneath the West Antarctic Ice Sheet. To obtain them, we are building a West Antarctica GPS Network (WAGN) of at least 15 GPS sites across the west antarctic interior-an area comparable to the area from the Rocky Mountains to the Pacific coast-over 2 years, beginning in the 2001-2002 austral summer.

The first summer, we initiated the WAGN network and tested the precision and velocities at the most critical sites. The embryonic network will begin to fill a major gap in GPS coverage by looking for potential bedrock movements. If crustal motions are relatively slow, meaningful results will only begin to emerge over the next 5 years or so. Once it is permanently established, however, the network should yield increasingly meaningful results. Indeed, the slower the rates turn out to be, the more important it is to start measuring early.

West Antarctic Ice Sheet bedrock is so scattered and remote that to erect a continuous string of permanent GPS stations would rival the building of the American transcontinental railroad. Instead, we plan to follow the multimodal occupation strategy, which entails roving receivers (based in permanent monuments set in solid rock outcrops) in place for only a short time at each site, providing data that can be ranged against permanent GPS readings elsewhere. Each of these "bases" can be converted in the future to a permanent, autonomous station when more logistics and satellite data linkage throughout West Antarctica are in place. When detectable motions occur, we can reoccupy the most critical sites, obtain more reliable velocities, and make decisions about reoccupying the entire network.

We expect the results of this project to establish important early indicators of crustal plate dynamics beneath the West Antarctic Ice Sheet. As scientists take these into account in refining their models, future measurements and a time-series of the geodetic data should gradually produce a more constrained picture of subglacial dynamics for the West Antarctic Ice Sheet-that is, plate rotations and both elastic and viscoelastic motions caused by deglaciation and ice-mass changes. (GO-087-M; NSF/OPP 00-03619)

TAMSEIS: A broadband seismic experiment to investigate deep continental structure across the east-west antarctic boundary.

Douglas Wiens, Washington University, and Sridhar Anandakrishnan, Pennsylvania State University.

Antarctica's outline looks generally like that of Australia, though half again as large; but beneath its enormous ice sheet lies evidence of its origin. East Antarctica has a bedrock continent-like foundation, while the ice sheet over West Antarctica-a third the area-in fact covers a series of islands. West Antarctica shares a geologic history with the Andes Mountains, the result of plates colliding and subducting. East Antarctica is more like a large chunk that broke free of the supercontinent Gondwanaland and drifted to a new position at the bottom of the world. The boundary between these two regions (with their disparate geologic pedigrees) is called the east-west antarctic boundary, and the crust and upper mantle here reveal many important and interesting distinctions that tell the basic story of the tectonic development of Antarctica.

In November 2000, we began making seismic measurements-using 3 different arrays and 44 seismic stations-all geared to evaluating geodynamic models of the evolution of Antarctica. To analyze the data, we will use a variety of proven modeling techniques, including body- and surface-wave tomography, receiver function inversion, and shear-wave splitting analysis.

One basic question is, How were the Transantarctic Mountains formed? Though widely considered a classic example of rift-flank uplift, there is little consensus about the exact mechanism. Many theories have been proposed, ranging from delayed-phase changes to transform-flank uplift. All of these make assumptions about the upper mantle structure beneath and adjacent to the rift-side of the mountain front.

Another focus will be the structure of the east antarctic craton, the highest ice block in the world. Was this anomalous elevation a prime driver in the onset of glaciation there? More to the point, how did it arise? Proposed models include isostatic uplift from thickened crust, anomalously depleted upper mantle, and thermally modified upper mantle, as well as dynamic uplift. How far the old continental lithosphere extends is also uncertain. In particular, it is not known whether the old lithosphere extends to the western edge of East Antarctica beneath the crustal rocks deformed during the Ross Orogeny (formation).

When completed and analyzed, this comprehensive set of data and theory testing will enable new maps of the variation in crustal thickness, upper mantle structure, anisotropy, and mantle discontinuity topography across the boundary of East and West Antarctica, providing a much enhanced foundation for understanding the geodynamics of the region. (GO-089-M; NSF/OPP 99-09603)

Logistics support for global seismographic network stations at the Amundsen-Scott South Pole and Palmer Stations.

Rhett Butler, Incorporated Research Institutions for Seismology.

Seismology, perhaps as much as any other science, is a global enterprise. Seismic waves resulting from earthquakes and other events can be interpreted only through simultaneous measurements at strategic points all over the planet. The measurement and analysis of these seismic waves are not only fundamental for the study of earthquakes, but they also serve as the primary data source for the study of the Earth's interior. To help establish the facilities required for this crucial scientific mission, IRIS (the Incorporated Research Institutions for Seismology) was created in 1985.

IRIS is a consortium of universities with research and educational programs in seismology. Ninety-seven universities are currently members, including nearly all U.S. universities that have seismological research programs. Since 1986, IRIS, through a cooperative agreement with the National Science Foundation (NSF) and in cooperation with the U.S. Geological Survey (USGS), has developed and installed the Global Seismographic Network (GSN), which now has about 126 broadband, digital, high-dynamic-range seismographic stations around the world; most of these have real-time communications.

The GSN seismic equipment at Amundsen-Scott South Pole Station and at Palmer Station was installed jointly by IRIS and USGS, which together continue to operate and maintain them. The GSN sites in Antarctica are vital to seismic studies of Antarctica and the Southern Hemisphere, and they contribute to the international monitoring system of the Comprehensive Test Ban Treaty. The state-of-the-art seismic instrumentation is an intrinsic component of the NSF effort to advance seismology and Earth science globally. (GO-090-P/S; NSF/OPP 00-04370)

Development of a luminescence dating capability for antarctic glaciomarine sediments: Tests of signal zeroing in the Antarctic Peninsula.

Glenn Berger, Desert Research Institute, and Eugene Domack, Hamilton College.

Paleoclimatology-the study and reconstruction of ancient weather and climate and their likely effects-is not an exact science. Climatic indicators, such as marine sediments that have been abundantly deposited around Antarctica over the past 2 million years, provide useful information about such phenomena as the waxing and waning of ice sheets, but only to the extent that these fossils can be accurately dated.

Traditionally, radiocarbon dating with the naturally occurring isotope carbon-14 has proved reliable for

specimens as old as 40,000 years, perhaps even 70,000 years, though problems such as the "reservoir effect" can limit its reliability and range. Moreover, increasing amounts of carbon-14 in the atmosphere have compromised its precision. A more recently developed method, photon-stimulated-luminescence sediment dating (photonic dating), has been used in temperate latitudes for aeolian and waterlain deposits and has proved reliable over a larger span of Quaternary time-from decades to hundreds of thousands of years. The question of whether this method can be reliably used in polar regions has yet to be answered, however.

Marine sediments in and around Antarctica pose special difficulty because polar conditions can limit the sunlight that detrital grains are exposed to. Since the thermoluminescent test involves reflecting the last time a sample was exposed to light (what is known as the clock-zeroing process), antarctic glaciomarine depositional settings and processes could undermine the reliability of photonic dating of antarctic marine sediments, and ages could be overestimated if grains were not exposed to daylight before deposition. Other processes could also compromise photonic dating. For example, transport of terrigenous suspensions by neutrally buoyant "cold-tongue" (mid-water) plumes may be common around Antarctica, yet the effect of such transport on luminescence zeroing is unknown. Typical marine cores taken near Antarctica may contain an unknown fraction of detrital grains from cold-tongue and near-bottom suspensions.

We will collect detrital grains from a variety of modern marine settings within the Antarctic Peninsula, where representative depositional processes have been documented and where logistics permit access.

By systematically studying the effectiveness of luminescence-clock-zeroing in antarctic glaciomarine settings, we hope to determine whether photonic dating can be reliably applied to antarctic marine sediments. In the process, we expect to develop refined criteria for selecting samples. If we can validate photonic-dating in this environment, scientists would gain a geochronometer extending well beyond the range of carbon-14 dating and be better able to answer a number of broader questions about past glaciations on and near the antarctic shelves. (GO-092-O; NSF/OPP 99-09665)

Antarctic Cretaceous-Cenozoic climate, glaciation, and tectonics: Site surveys for drilling from the edge of the Ross Ice Shelf.

Bruce P. Luyendyk and Douglas Wilson, University of California-Santa Barbara.

Many of the questions on the evolution of the East and West Antarctic Ice Sheets, antarctic climate, global sea level, and tectonic history of the West Antarctic Rift System can be answered by drilling into the floor of the Ross Sea. We will therefore conduct site surveys for drilling from the Ross Ice Shelf into the seafloor beneath. Climate data for this sector of Antarctica are lacking for the Cretaceous and Early Cenozoic. Questions include,

- Was there any ice during the Late Cretaceous?
- What was the antarctic climate like during the Paleocene-Eocene global warming?
- When was the Cenozoic onset of antarctic glaciation? When did glaciers reach the coast and when did they advance onto the margin?
- Was the Ross Sea shelf nonmarine in the Late Cretaceous? If so, when did it become marine?

Tectonic questions include,

- What was the timing of the Cretaceous extension in the Ross Sea rift and where was it located?
- What is the basement composition and structure?
- Where are the time and space limits of the effects of Adare Trough spreading?

Sampling at four drill sites was completed in the early 1970s but had low recovery and did not sample the Early Cenozoic. Other drilling has been restricted to the McMurdo Sound area of the western Ross Sea, and results can be correlated for the Victoria Land Basin but not eastward across basement highs. Further, Early Cenozoic and Cretaceous rocks have not been sampled.

Our surveys (including core samples and long profiles and detailed grids over potential drilling sites) will be conducted a kilometer or two north of the ice-shelf front. In 2 to 4 years, the northward advance of the shelf will cover surveyed locations and drilling can begin. The calving of giant icebergs from the ice front in the eastern Ross Sea have exposed 16,000 square kilometers of seafloor that has been covered for decades and has therefore not been explored. We will be able to map structure and stratigraphy below unconformity RSU6 farther south and east, study the place of Roosevelt Island in the Ross Sea rifting history, and determine subsidence history during the Late Cenozoic in the far south and east. Finally we will observe current sedimentary processes beneath the ice shelf in the newly exposed areas. (GO-152-O; NSF/OPP 00-88143)

Relative frequency and phase of extreme expansions of the antarctic ice sheets during the late Neogene.

Phillip Bart, Louisiana State University.

Expansions and contractions of the antarctic ice sheets have undoubtedly had a profound influence on the Earth's climate and global sea level. But the cryosphere in Antarctica is not a single homogenous entity. Science has yet to embrace its three primary components-the East Antarctic Ice Sheet, the West Antarctic Ice Sheet, and the Antarctic Peninsula Ice Cap-into a unified theory. Among these systems may be found differences in ice volume, substratum elevation, ice-surface elevation, and latitude.

Various lines of evidence do show, however, that the extent of ice in all three ice sheets has undergone significant retreats and advances; future episodes therefore appear inevitable. But exactly how and why the ice has fluctuated in this way is not certain. According to one line of reasoning, the land-based East Antarctic Ice Sheet has been relatively stable, experiencing only minor fluctuations since forming in the middle Miocene; by contrast, the marine-based West Antarctic Ice Sheet has been dynamic, waxing and waning frequently since the late Miocene. A conflicting hypothesis has the ice sheets advancing and retreating at about the same time.

Building on previous seismic-stratigraphic investigations of the continental shelves, we will use high-resolution seismic technology to focus on the frequency and phase of extreme advances of the ice sheets to the continental shelf. The data suggest a couple of useful scientific inquiries:

First, did extreme advances of the East Antarctic Ice Sheet and West Antarctic Ice Sheet occur across the shelf at about the same times and frequencies? This evaluation is possible because the East Antarctic Ice Sheet drains into the western Ross Sea continental shelf (Northern Basin), while the West Antarctic Ice Sheet drains into the eastern Ross Sea (Eastern Basin). Regional grids of high-resolution seismic data have been collected, but they are incomplete and cannot be used to determine the stratigraphic correlations from the Northern Basin to the Eastern Basin. We plan to collect high-resolution seismic data (approximately 2,000 line-kilometers) to

address this issue.

Second, did the Antarctic Peninsula Ice Cap advance frequently across the continental shelf? Some investigators have inferred that it has advanced across the shelf at least 30 times since the middle Miocene. If true, that activity would be an order of magnitude more frequent than the advances of the East Antarctic and West Antarctic Ice Sheets. Others interpret the seismic reflections differently and argue that the advances of the Antarctic Peninsula Ice Cap were far fewer. The existing high-resolution seismic grids from the Antarctic Peninsula contain only one regional strike line on the outer continental shelf; we collected high-resolution seismic data (approximately 1,000 line-kilometers) during a January 2002 cruise to the Antarctic Peninsula.

As part of this project, we are integrating our research into a graduate-level course at Louisiana State University and are also developing a pilot outreach program with a Baton Rouge public high school. Responding to scientific standards the Louisiana Department of Education recently adopted to reflect what 9th through 12th grade students should be able to do and learn, we are framing an experience to convey the excitement of conducting scientific research as a way to encourage them to pursue earth science at the university level. (GO-154-N; NSF/OPP 00-94078)

Aeolian processes in the McMurdo Dry Valleys, Antarctica.

Nicholas Lancaster and John Gillies, Desert Research Institute.

The McMurdo Dry Valleys provide a unique natural laboratory where scientists can study some fundamental processes in nature. Geomorphology is the study of landforms and the processes that shape them: for example, particles (sand, dust, snow, etc.) blown by the wind across a characteristic terrain. Wind-shear-stress partitioning analysis can create models to predict how such wind-borne particles, en route to a surface, may be affected by intervening elements that have a certain roughness-boulders, in the case of the McMurdo Dry Valleys. Ongoing studies of such regions (that is, sparsely vegetated to unvegetated rough surfaces) should provide models relevant to other arid areas on Earth and on Mars, as well as a range of rocky desert and sand sheet sites.

Using novel instrumentation called Irwin Sensors that was recently developed and has been tested in field and laboratory wind tunnel experiments, we will conduct studies of boundary layer winds and surface shear stress at four to six locations. This work will contribute to the testing and improvement of existing theoretical models for shear-stress partitioning. We hope the research will lead to the development of an improved and universally applicable model for estimating sediment transport by wind on surfaces that are covered by varying densities of nonerodible roughness elements. (GO-183-O; NSF/OPP 00-88136)

Ferrar basaltic tuff-breccias formed by direct eruption: Evaluating a hypothesis.

David Elliot, Ohio State University.

The Gondwanaland supercontinent broke up during Mesozoic times, and one part, now Antarctica, moved to the geographic south pole. A major magmatic event accompanied the breakup of the landmass. Voluminous basaltic magmas were erupted at the surface, and intrusive sills and dikes were emplaced at depth within the underlying sedimentary sequence. The record of this process in Antarctica shows extrusive rocks that include thick tuff-breccias (coarse pyroclastic rocks), believed to have formed by subsurface explosive interaction of basaltic magma and water in aquifers. This clash of materials with dramatically different temperatures is known as phreatomagmatic process.

Volcanic fields are commonly found in modern rift settings and include sites where rising magmas interact

explosively with water in aquifers or at the surface. The volcanic fields in parts of Antarctica, however, are unique. Compared with other well-documented examples, these basaltic pyroclastic rocks differ in terms of areal extent and thickness of deposits, depth of magma/water interaction, and dominance of basaltic tuff-breccia. We expect study of the paleovolcanology of these rocks to yield important new information on the origins and emplacement mechanisms of tuff-breccia deposits, as well as on the evolution of volcanic fields in which tuff-breccias form a significant component.

To better describe the processes involved in forming these exceptionally thick tuff-breccias, we hope to

- document the three-dimensional architecture of the basaltic pyroclastic rocks,
- establish the depth of magma/water interaction and evaluate aquifer recharge,
- establish the nature and extent of the volcanic field and its paleovolcanologic setting, and
- evaluate the hypothesis that these tuff-breccias are the result of direct eruption from volcanic vents.

Building on reconnaissance work, we expect the results of this study to have broad implications for understanding how phreatomagmatic processes form tuff-breccias, as well as the tectonic settings in which they occur. Results are also expected to develop the paleovolcanologic setting of the Transantarctic Mountains during the Jurassic. (GO-290-O; NSF/OPP 00-87919)

High-precision GPS survey support.

Bjorn Johns, University Navstar Consortium (UNAVCO).

UNAVCO provides year-round support for scientific applications of the global positioning system (GPS) to the U.S. Antarctic Program, which is supported and managed by the National Science Foundation's Office of Polar Programs. This support includes preseason planning, field support, and postseason followup, as well as development work for new applications. UNAVCO maintains a "satellite" facility at McMurdo Station during the austral summer research season, providing a full range of support services, including geodetic GPS equipment, training, project planning, field support, technical consultation, data processing, and data archiving.

UNAVCO also operates a community differential GPS base station that covers McMurdo Sound and Taylor Valley, provides maintenance support to the MCM4 continuous GPS station as contractual support to the National Aeronautics and Space Administration's GPS Global Network, and supports remote continuous GPS stations for scientific investigations.

Using GPS, vector baselines between receivers separated by 100 kilometers or more are routinely measured to within 1 centimeter (that is, 100 parts per billion). UNAVCO is also able to support researchers who are investigating global, regional, and local crustal motions where maximum accuracy (in the millimeter range) of baseline measurement is required. GPS measurements using portable equipment can be completed in a few hours or less. Such expediency lends itself to research applications in global plate tectonics, earthquake mechanics, volcano monitoring, and regional tectonics. (GO-295-O; NSF/OPP 99-03413)